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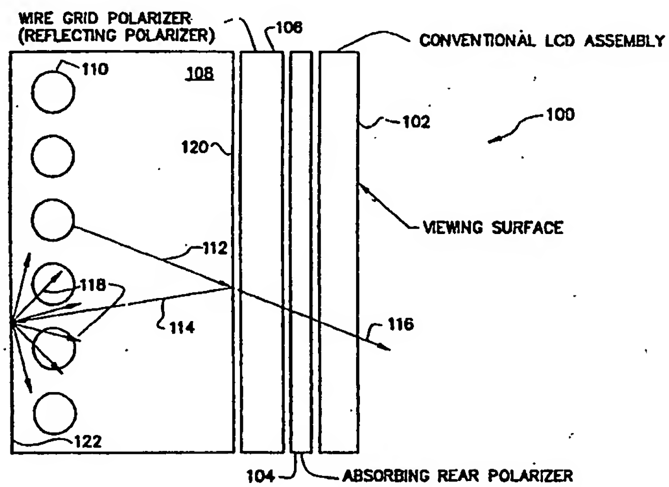
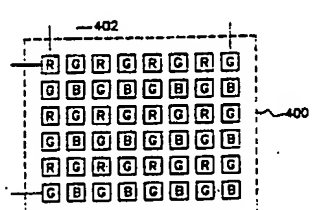
(57) Abstract

A radiant energy conservation LCD display (100) includes a cavity (108) having a highly reflective, diffusing interior surface (107). A back light (110) is mounted within the cavity (108). A filter (104, 106) is located forward of the back light (110) for transmitting filtered light (116) of specified frequencies and for reflecting out of band light (114) rather than absorbing it. The filter (104, 106) includes a reflecting polarizer (106) for transmitting a light (112) having a first polarization (116) and reflecting a light having a second polarization (114).





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BACKLIT DISPLAY

Field of the Invention

The present invention relates to the field of back lit displays and, more particularly, to displays including, for example, LCD, ferroelectric displays, signboards, projection displays, and other similar illuminated display devices and systems.

Discussion of the Prior Art

Prior art back lit displays suffer from poor luminance uniformity, insufficient luminance and excessive power consumption which generates unacceptably high levels of heat in and around the display. Prior art displays also exhibit a non-optimal environmental range due to dissipation of energy in temperature sensitive components. Prior art displays also feature excessively large back light assemblies. Increasing the luminance of displays such as, for example, liquid crystal displays (LCDs) has been accomplished in the prior art by increasing the electrical power for illuminating the back light. However, such an approach has inherent and unavoidable drawbacks, as discussed hereinbelow.

The construction of a typical prior art back lit twisted neumatic active matrix liquid crystal display (TN AMLCD) is illustrated in Figure 1. A typical display 10 usually includes display drive electronics 14, a fluorescent lamp 12, a diffuser 16, a first polarizer 18, a spatial light modulator 20, a color filter and black matrix 22 and a second polarizer 24 adjacent the front surface of the display 26. The back light produced by the fluorescent lamp 12 is diffused to achieve uniformity and generally directed according to viewing angle requirements. In the case of a TN AMLCD, the back light is also polarized.

Light which is incident on the back of the display surface is twisted and passed through the spatial light modulator 20 or absorbed in crossed polarizers so as to form an image for the viewable front surface 26. Using the architecture of Figure 1 with a back light assembly the viewable surface of the TN AMLCD display may be perceived as not bright enough for avionic applications. This is true even for the brightest available back lighting. This shortcoming is a consequence of the optical losses inherent in the construction of the display. Another important application is in the AMLCDs use in lap top personal computers where display efficiency essentially determines the battery life.

Various means may be employed to increase back light luminance in such displays. For example, a bright back light, on the order of 7000 fL surface luminance, may be constructed by using a fluorescent lamp 12 having maximum bulb area and driving it at maximum cathode current. Sometimes additional brightness may be obtained by interleaving lamps. The main thrust of the aforedescribed techniques is to increase the lamp power density of the back lit area as much as possible. Even though fluorescent lamps of this type are efficient, they still consume considerable amounts of power in order to produce light. Unfortunately, the resulting high luminance of the fluorescent lamps increases the amount of electrical power and generates excessive heat. In battery powered applications, the use of high powered lamps dramatically reduces battery life or increases the size of batteries required for operation.

When fluorescent lamps are operated at sufficiently high power levels to provide a high degree of brightness for a cockpit environment, for

example, the excess heat generated may damage the display. To avoid such damage, therefore, the excess heat must be dissipated. Typically, heat dissipation is accomplished by directing an air stream to impinge upon the components in the display. Unfortunately, the cockpit environment contains dirt and other impurities which are also carried into the display with the impinging air. Presently available LCD displays cannot tolerate the influx of dirt and are soon too dim and dirty to operate effectively.

Another drawback of increasing the power to a fluorescent lamp is that the longevity of the lamp decreases dramatically as ever higher levels of surface luminance are demanded. The result is that aging is accelerated which may cause abrupt failure in short periods of time when operating limitations are exceeded.

Figures 2A and 2B show measurements of a TN AMLCD image surface which exhibits the absorbance of light energy for collimated light at 632.8 nm. These measurements were taken with a HeNe laser linearly polarized excitation source which was spatially under sampled by the AMLCD's apertures. The laser source's polarization was aligned to peak measured data. Radiation that is neither reflected nor transmitted is absorbed, thus for light at 10 degrees horizontal angle of incidence as shown by curves 204, 206, about 9% of the incident light is transmitted.

Curves 200, 202 indicate that about 10 - 11% of incident light at a 10 degree horizontal angle of incidence is reflected. The data shows that about 80% of the light is absorbed by conversion to heat energy. For typical color TN AMLCD only between 2 and 4% of white unpolarized light of a fluorescent back light passes out the front surface of the display. This is

a problem for the visual performance of the display and it limits the environmental range of the display due to the inability to dissipate the excess heat energy. Excess power dissipation also increases the cost of operation for the display.

Prior art back lit display designs have attempted to solve the display luminance and efficiency problems by several means including those listed hereinbelow:

1. The most obvious technique for increasing display luminance is to increase back light intensity. This has limitations according to the back light needed. More luminance inevitably requires a larger, more powerful, more expensive luminance source.

2. Prior art system designs have also attempted to increase brightness by selection of color filters which do not span as great a color gamut. This tradeoff of brightness for color sacrifices the color nature of the display in order to increase luminance. This is not acceptable for avionic applications, for example, because some avionic symbology is differentiated from other avionic symbology on the basis of perceived color difference. Even if the resultant lack of colors is ignored, such an approach still does not yield a sufficient gain in luminance to solve the brightness problem.

3. Another technique is to decrease the space on the display surface which is used for optically inactive elements, such as row and column address structure or transistor area.

Efforts in this direction have decreased yield in the manufacturing of displays, and/or limited pixel density, causing poor image quality.

4. Prior art methods have attempted to recover light from the back light by placing it within a reflective cavity. Where fluorescent lamps were employed under the theory that light emitted off the back side of the lamp may be captured as well as light from the side of the lamp which was directly viewable from the front side of the display. However, to be effective, such a reflective cavity must operate in conjunction with the display surface and that has not been accomplished prior to the present invention.

Background of Wire Grid Polarizers

Traditional polarizers offer the advantages of being inexpensive while exhibiting a good extinction ratio over a broad angle of incidence. They also perform well over the entire visible spectrum from about 400 to 650 nanometers wave length. The downfall of traditional polarizers as applied to LCDs emanates from the absorption of the incident radiant energy which is not aligned with the polarizer's transmissive polarization axis. This leads to a need for increased source illumination which traditionally has meant more electrical power consumption, as noted hereinabove.

In 1888, Heinrich Hertz first used a wire grid as a polarizer for the then newly discovered radio waves. In 1911 noble metal wires 25 micrometers in diameter were used as a polarizer. At that time, the implication was clear that finer wire grids would polarize at still shorter wavelengths. C.W. Peters

and W.K. Parsley of the University of Michigan extended the application into the microwave region of the spectrum in 1954.

Polaroid's G. Bird and M. Parrish applied a wire grid in the near-infrared region of the spectrum in 1960. Similar infrared polarizers are now commercially available for use as optical components. Examples may be found in the Newport Research Corp. 1991 catalogue. However, despite the availability of the aforesaid research for over 75 years, no one has designed a wire grid polarizer for the visible light wave lengths until the present invention. The use of such a reflecting polarizer in a radiant energy conservation system for a back lit display was heretofore unknown.

Summary of the Invention

The invention provides a radiant energy conservation LCD display including a cavity having a highly reflective, diffusing interior surface. A back light is mounted within the cavity. A filter is located forward of the back light for transmitting filtered light of specified frequencies and for reflecting out of band light rather than absorbing it. The filter includes a reflecting polarizer for transmitting a light having a first polarization and reflecting a light having a second polarization.

In contrast to the prior art it is one objective of the present invention to reduce the heating of the active matrix caused by light absorption.

It is another objective of the present invention to provide an LCD having increased display brightness.

The present invention, for the first time, discloses the modeling of a back lit display according to the excitation and absorbance of radiant energy. Figure 3, described in more detail hereinbelow, shows

the opportunity for increased display luminance based upon changing the elements of the display so that the elements accomplish their function in a manner which conserves radiant energy. The radiant energy which is not transmitted out of the front surface of the display is reflected into the back light cavity where it is advantageously scattered, randomly polarized and rereflected back to the display. This return of energy to the system for reuse is unfortunately limited by the sources of absorbance which are present in the optical elements of the display. Energy lost by transmittance out of the front surface of the display is the only desirable loss.

The return of radiant energy to the system changes the sensitivity of the display construction to limitations which were heretofore thought to be fundamental constraints. For example, aperture ratio (herein defined as the ratio of pixel active area to total area) was thought to be a direct loss, whereas in a perfectly non-absorbing system, the aperture ratio has no affect at all on display luminance. By constructing a specularly reflective aperture mask which exactly aligns with the LCD's spatial light modulator's apertures, this previous limitation can largely be overcome.

Another design feature of the invention is back light design. In a reflecting back light cavity, increasing back light intensity does not necessarily increase display luminance in direct proportion. Back lights absorb radiant energy as well as create it. Here, if back light absorbance increases, for example, because lamp size increases, the increase in display output luminance may be considerably less than proportional to increased lamp input luminance. So a basis for display optimization is established.

Different optimization exists for display efficiency than for total luminance.

The invention provides design of displays as an integrated low absorbance unit, involving the back light as part of a total optical assembly in which components are designed on the basis of their ability to function with minimum absorbance of radiant energy. This involves optimization of the paths which return light to the display glass and minimization of absorbance sources. There are several outstanding sources of absorbances which must be considered including polarizers, lamps, pixel address structures, color filters, and back light cavity. Some examples of recommended changes to back lit display structures in accordance with the present invention are discussed hereinbelow.

1. An addressing structure for the image surface is constructed using reflective metalization. For example, aluminum is advantageously selected for use in preference to gold or nichrome based upon its reflectance advantage. This is especially advantageous in the blue region of the spectrum. Alternatively, in order to preserve polarization, a spectrally reflective mask structure aligned with the pixel structure and covering all non-active portions of the image surface may be used as indicated in Figure 4, which is discussed in more detail hereinbelow. Such a mask structure may advantageously be located physically very close to the active portion of the image glass assembly on the side which may advantageously return energy to the back light cavity. The function of such

a reflective mask may advantageously be to return radiant energy which may not otherwise pass through the optically transmissive region of the pixel. On the front surface of the display, a black matrix may advantageously be employed to absorb incident radiant energy and thereby increase contrast ratio.

2. The present invention further contemplates design of the color filters for a display to reflect untransmitted light. Within a pixel, light of a particular color, blue for example, may advantageously be transmitted and red and green light may advantageously be returned to the integrating back light cavity. Instead of using a dye or pigment based filter which absorbs out of band energy as is done in the prior art, dichroic filters which reflect out of band energy are contemplated to be used by some example embodiments of the present invention. Dichroic filters have relatively steep roll off characteristics as compared to the roll off characteristics of traditional dye or pigment filters. The relatively steep roll off characteristics of dichroic filters advantageously results in a broader color gamut than may be experienced in displays using other types of filters.

3. Further, in accordance with the present invention, a reflective polarizer may advantageously be placed between the back

light and the rear polarizer where the rear polarizer is an absorbing polarizer. Light reflected off the address structure mask or the color filters may advantageously pass through the reflecting polarizer and return to the back light cavity. Incident light polarized in the same axis as the polarization axis of the rear absorbing polarizer may advantageously be transmitted from the back light cavity to the display. Incident light of the complementary polarization may advantageously be returned to the back light cavity where it may advantageously be reflected back toward the reflecting polarizer. It is important that the lighting cavity's reflecting surface scramble the polarization of the incident light so that on each circuit between the reflecting polarizer and the reflecting cavity, at least one-half of the light is polarized for possible transmission through the display surface.

4. The present invention further contemplates a reflective cavity design which does not trap light. Since prior art back light cavity designs are not optimized on the basis of minimum radiant energy loss, such designs require inordinate reflections to return untransmitted light to a useful path. Thus, the geometry of the reflecting surfaces, material selection, and relation to other optical components such as back light lamps are important to the minimization of the effects of absorbing

material.

For example, in accordance with the present invention a reflective cavity may be employed advantageously having rounded corners instead of square corners. Materials such as Spectralon (TM) coating may advantageously be used instead of white paint or aluminum. Spectralon (TM) coating is available from Labsphere, Inc. P.O.Box 70, North Sutton, NH 03260, USA.

To the extent that the flux density is non-uniform, it is possible for absorbing material which intercepts that flux to have a disproportional effect on performance. These limitations are discussed hereinbelow through use of an integrating sphere example.

5. The present invention further provides for the minimal use of diffuser elements. Diffuser elements absorb light because they introduce an inordinate increase in the reflections which a ray of light will encounter before reaching the imaging surface. Each of these reflections, even if they are very low loss, accumulates and increases total radiant energy loss. Diffusers cannot be placed between the reflecting polarizer and the rear surface of the glass. In a display designed in keeping with the principles of the invention, any directional elements or diffuser elements may be placed between the back light and the reflecting polarizer.

6. Displays based on radiant energy conservation in accordance with the invention have a sensitivity to the order in which optical elements are placed. Hence, colors may advantageously be refiltered using dichroic designs with pass bands that are designed to accommodate the viewing angle of the display followed by a black matrix and absorbing color filter structure on the viewed side of the display. In one alternative embodiment of the invention, some compromise between viewing angle for color fidelity and radiant energy conservation may be tolerated.

7. The reflecting properties of the back light cavity are also important in designing a display according to the principles of the invention. To improve luminance uniformity, the reflectance of the back light cavity may advantageously be diffuse, not only reflecting but scattering light and scrambling the incident polarization. Display luminance uniformity is increased through the same means which conserve radiant energy. A more uniform luminous flux density results from the non-specular reflections off of the back light assembly's back wall and from the fluorescent lamp than is obtained with an absorbing LCD assembly. By conserving and reflecting the radiant energy normally absorbed in the LCD assembly, more radiant energy is reflected from the areas between the fluorescent lamp's segments, effectively creating a more

uniform luminous source for the LCD assembly.

Brief Description of the Drawings

Figure 1 schematically illustrates the construction of a typical prior art back lit twisted neumatic active matrix liquid crystal display (TN AMLCD).

Figures 2A and 2B show measurements of a TN AMLCD image surface which exhibits the absorbance of light energy for collimated light at 632.8 nm.

Figure 3 graphically shows the opportunity for increased display luminance based upon changing the elements of the display so that they accomplish their function in a manner which conserves radiant energy.

Figure 4 shows the placement of color filters made from gels in an assembly which was substantially absorbing made from photographic tape having 4% reflectivity placed on a 0.060 inch soda lime glass substrate.

Figure 5 shows the spectral characteristics of Kodak Wratten gel filters.

Figure 6 shows the spectral characteristics of dichroic filters used in one aspect of the invention to reflect out of band light into the back light assembly while transmitting light which falls within the pass band of the filter.

Figure 7 illustrates one example of a reflecting back light cavity as contemplated by the invention.

Figure 8 illustrates an alternative front glass for one embodiment of the invention which was constructed using color separation filters placed in a film matrix.

Figure 9 graphically shows a measured reduction in light as a function of exposed surface area of a particular absorber as commonly found in LCD displays.

Figure 10 schematically illustrates an LCD utilizing a reflective polarizer in accordance with one aspect of the invention.

Figure 11 schematically illustrates increased contrast for traditional LCDs under high ambient illumination.

Figure 12 is a simplified illustration of loss of an LCD's traditional advantage under high ambient illumination.

Figure 13 graphically illustrates experimentally measured relative absorption properties of each of a fluorescent bulb, diffuser, and polarizer.

Detailed Description of the Preferred Embodiment

Theory of Operation of the Invention

In order to promote a better understanding of the invention a description of the theory for increasing liquid crystal display (LCD) brightness through conservation of radiant energy is provided hereinbelow. In conventional LCDs around 90% of the light energy created in the fluorescent lamps used for back lighting is converted to heat through absorption by materials within the display.

The interaction of radiant energy with materials is described by transmission, reflection, or absorption. Experiments conducted at Honeywell Inc., Defense Avionics Systems Division in Albuquerque, New Mexico used a commercially available integrating sphere to measure absorption of various materials found in typical back lighted displays. Such materials include, for example, fluorescent bulbs, diffusers, and other components.

By conservation of energy, the total radiant energy which exits an integrating sphere must equal the sum of the input radiant energy minus the amount of energy lost to absorption. For any particular

integrating sphere, calibration of the loss can be done using a known luminous source. . Such sources are well known in the art. One important characteristic to be noted is that the integrating sphere need not be perfect in order to be characterized and used. In fact the only requirement is that the sphere be calibrated to account for loss by absorption.

The back light assembly for an LCD may be regarded as an integrating sphere with a huge exit aperture. The back light assembly of an LCD contains materials with less than ideal reflective properties. The goal of the experiments was to characterize these materials to develop an understanding of their effect on the efficiency of our back light cavity.

There are several factors which limit the accuracy of this approach. One of these is the lack of spherical symmetry and therefore lack of uniformity of luminous flux within the integrating cavity. Also, a fluorescent bulb used as the LCD's light source cannot accurately be represented as a point source within the lighting cavity. These two factors make the amount of energy absorbed a function of material placement and shape. These effects can be reduced by using diffuse reflecting surfaces instead of specular reflecting surfaces and by paying some attention to the size and distribution of the fluorescent light source within the reflecting cavity.

This description details how to use an integrating sphere to measure the absorbance of materials. The absorbance obtained is scaled to apply to a back light assembly design. The effects which may be achieved if certain absorptive elements are changed into perfectly reflective elements is quantified. The result is a family of opportunity curves shown in Figure 3 which quantify the potential

advantage of using radiant energy conservation techniques.

Experimental Procedure and Data

The Honeywell light absorption experiments measured the decrease in light as the amount of absorptive material was increased within a luminance integrating sphere purchased from Hoffman Engineering model number LS-65-8C.

Light absorbing material was made in two different shapes, spheres and disks. Each shape was fabricated from metal and made in various diameters which were sandblasted to achieve a rough texture and painted flat black to achieve approximately 100% absorption of incident visible light. Each sphere or disk was individually placed inside of the integrating sphere, and the light was measured through the exit aperture of the integrating sphere using a Pritchard 1980A photometer. Figure 9 shows the measured reduction in light intensity as a function of the exposed surface area of the particular absorber.

The vertical axis 90 of Figure 9 is the measured luminance plotted as a percentage of the integrating sphere's light output normalized to 100% for the condition where no additional absorptive materials were added to the integrating sphere. The horizontal axis 92 of Figure 9 is the surface area of the added absorber divided by the internal surface area of the integrating sphere expressed as a percentage. The horizontal axis 92 was selected to allow for extrapolation of the measured data to LCD lighting cavity applications.

The squares 94 on Figure 9 represent the measured data for sphere shaped absorbers, and the circles 96 represent the data for the disk shaped absorbers. A first curve 98 was plotted for the measured sphere

data and a second curve 100 was plotted for the measured disk data. The difference between the first and second curves indicates the effect of absorber shape within the experimental apparatus.

Modeling of Absorptive Materials within an Integrating Sphere

The continuous curve 98 underlying the measured disk data shown in Figure 9 is predicted data for the integrating sphere with an average internal reflectance of 96.5%. The basis for calculations used in the experiment is found in two references: Illumination Engineering, J. B. Murdoch, 1985, pp 45-48, and Applied Optics, Volume I, L. Levi, 1968, pp 31-32.

Murdoch presents an equation which calculates the exitance at the integrating sphere's exit aperture. The exitance, having units of lumens per unit area and the luminance, having units of candela per unit area, are directly proportional at the integrating sphere's exit aperture. Murdoch's equation is

$$E = (p\ \Phi) / (A_t\ (1 - p))$$

where E is the exitance, p is the average reflectance of the sphere, Φ is the luminous flux of the sphere's light source, and A_t is the internal surface area of the integrating sphere.

By placing absorptive materials inside of the integrating sphere the average reflectance (p) of the sphere was decreased. The reflectance of the sphere is dependent upon two factors:

(1) the reflectance of the wall of the sphere, p_m; and (2) the less reflective surfaces within the sphere (i.e., the exit aperture, and the light source entrance aperture).

The reflectance of the sphere with no absorbers added can be estimated using the following equation

$$p = p_m - (A_o / A_t)$$

where A_o is the area of the sphere's exit aperture. Loss due to the exit aperture must be normalized by internal reflecting area because it determines the flux density at the exit aperture.

To calculate the effect of adding light absorbers, another decrease to average reflection is introduced as in the next equation,

$$p = p_m - (A_o / A_t) - (A_a / A_t)$$

where A_o is the exposed surface area of the absorber. For the spheres A_a is equal to the surface area of the sphere and for the disks it is equal to the area of one side of the disk.

Substituting this expression for reflectance into Murdoch's equation for exitance yields

$$E = \{\Phi[p_m - (A_o / A_t) - (A_a / A_t)] \}/\{A_t[1 - p_m + (A_o / A_t) + (A_a / A_t)] \}.$$

The flux, Φ, is a constant as long as the light source does not change, and the quantities (A_o / A_t) and p_m are constant for the integrating sphere. Thus the exitance is a function of the absorber's surface area relative to the integrating sphere's surface area.

The variable, (A_a / A_t) , for the horizontal axis of Figure 9 is in both the numerator and denominator of the above expression. The predicted data of Figure 9 was calculated using this expression with p_m equal to 0.965.

Application of Model

Figure 3 graphically exhibits the extension of this energy loss model to the conditions expected for a typical avionics display. This application is intended to serve only as an illustration to aid in understanding the invention and the invention is not limited to this specific display. The bottom curve 310 reflects the operating condition for a

conventional display. The other curves 302 - 308 represent the potential gains associated with the addition of the proposed perfect reflective optical components. For example, curve 308 represents the addition of a reflective aperture matrix. Curve 306 represents the addition of reflective polarizers to the display of curve 308. Curve 304 represents the addition of reflective color filters to the display of curve 308. Curve 302 represents a display having reflective aperture masks, reflective color filters and a reflecting polarizer such as a wire grid polarizer.

For each curve of Figure 3 the effective exit aperture, A_o is changed to indicate the best case performance when adding the new reflective components. For the purposes of this disclosure, an effective exit aperture is defined as a component wherein light which is completely absorbed can be regarded as having passed out an exit aperture. Substituted materials which reflect light which was absorbed can be modeled by reducing exit aperture area.

The lighting cavity's size was assumed to be 6 x 8 x 2.3 inches to calculate the internal surface area of the integrating cavity (A_t). The average reflectance of the cavity, p_m, was assumed to be 1.0, and the horizontal axis variable, (A_a / A_t), is expressed as a percentage on the Figure 3 ranging from 0% to 10%. The bottom curve 310 was calculated with A_o equal to the area of the display surface, about 48 sq. in. This assumes that all light incident on the rear polarizer of the LCD module is either absorbed or transmitted. The normalized luminance of 100% is established as a reference based on the prior art exhibited by curve 310.

By making the row and column address lines

reflective on an LCD with an aperture ratio of 55%, the transmitted light increases as shown with curve 308 of Figure 3. The effective exit aperture, A_o decreases to 26.4 square inches for this condition.

Curve 306 reflects the potential gain associated with adding a wire grid polarizer to an LCD module with a reflective row and column address structure. The effective aperture is decreased to 13.2 square inches based upon the assumption that the light previously lost in the rear polarizer is now recovered by reflection within the lighting cavity. Previously the lost light amounted to about 50% of the total light produced by the back lights.

To understand the effect of particular components or materials which are included within the back light cavity, the absorption of each component can be quantitatively estimated. This can be accomplished by repeating the integrating sphere experiment using the components or representative pieces of the components to measure the light loss. From this measured data an equivalent black disk surface area can be determined. This equivalent surface area can then be scaled by the ratio of the proper size for the material which will be present within the lighting cavity divided by the size of the measured piece.

Measurements were made to determine which optical element within an LCD's optical assembly was the largest consumer of radiant energy. These measurements showed the tremendous potential gains in luminous efficiency which would result from radiant energy conservation. They also revealed that the rear polarizer was the most significant absorptive component. Figure 13 shows the relative absorption of a fluorescent bulb, diffuser, and traditional polarizer.

Table 1 hereinbelow shows the light loss for sections of an ATSD D size fluorescent lamp where the bulb's inner diameter is 0.476". For each lamp length, the lamp was fitted with end caps made of Spectralon (TM) prior to insertion into the integrating sphere. The length shown in table 1 is the distance between the two Spectralon end caps.

TABLE 1

Fluorescent Bulb Lengths	Percentage of Light Decrease
0.9925	2.13
2.071	3.83
2.79	5.0

Because the lamp absorption scales approximately with lamp surface area, the absorption of a 48.3 inch long lamp with a 0.476" inner diameter can be calculated based upon this measured data. Dashed line 312 at 2.88% represents the amount of relative absorption associated with a fluorescent lamp having a 15 mm diameter, and 1226.6 mm length.

A section of a milky white diffuser was placed inside of the integrating sphere and the light loss was measured. The diffuser piece had an exposed surface area of 1.565 square inches. The measured loss was 5.96% for this piece. A black disk with a surface area of 0.3219 square inches will exhibit this percentage of loss from the Hoffman Engineering integrating sphere. Scaling the loss for a diffuser which is 48 square inches and placed inside of the lighting cavity gives 6.15% of absorptive material relative to the lighting cavity. Taken together the fluorescent bulb and the diffuser result in 9.03% of absorptive material within the lighting cavity.

The predicted gains associated with the addition of the reflective row and column structure and the reflective color filters to one example display are

shown by curve 304 representing an effective aperture = 6.6 sq in. Curve 304 assumes the aperture is equal to the area of the red pixels on the display surface.

Curve 302 represents an effective aperture = 3.3 sq in and is the predicted performance for a display employing a wire grid polarizer, reflective color filters, and a reflective row and column structure. The effective aperture is reduced by a factor of 2 because the loss associated with the rear polarizer may advantageously be approximately 50%.

It should be noted that the data shown in Figure 3 are for perfectly efficient conditions. All light that is incident is either transmitted or reflected and all light which is reflected is assumed to be re-incident to the LC glass surface after reflection. It is also important to realize that only a 10% efficiency for the new components in a system design will result in approximately 120% increase in brightness for the composite LCD.

Apparatus and Method of the Invention

Having described the theory of the invention, several example embodiments and elements of the invention are presented hereinbelow. The examples described are intended to illustrate the principles of the invention and the invention is not limited to the specific embodiments described herein.

Referring now to Figure 7, one example of a reflecting back light cavity as contemplated by the invention is illustrated. A reflecting back light cavity 700 was constructed using Spectralon (TM) material to coat inside wall 706. Spectralon (TM) was selected because of its excellent diffuse reflectance properties across the visible spectrum. A fluorescent bulb 720 was installed to provide a representative source of illumination. To demonstrate the effects of

a conventional LCD structure, a front glass 710 was constructed with 1 by 1 inch pixels in a 6 x 8 inch active area 702.

Figure 4 shows the placement of color filters 402 made from Kodak Wratten gels in a front glass assembly 400 which was substantially absorbing made from photographic tape placed on a 0.060 inch soda lime glass substrate. The photographic tape had 4% reflectivity. This is intended to simulate the approximate aperture ratio (51%) and absorbance of matrix displays with RGGB color filter structure and about 170 pixels per inch aperture density. Such a front glass surface represents the conventional approach to manufacturing flat panel displays, in this case with a flat field white image displayed.

Figure 5 shows the spectral characteristics of the Kodak Wratten gel filters used in the construction of the front glass assembly 400. Note that the vertical axis 500 represents transmittance and the horizontal axis 502 represents wave length in nanometers. Curves 504, 506 and 508 respectively represent blue, green and red light transmittance characteristics. Note the substantial overlap area at point 510 between the blue and green filters. Such an overlap blurs color distinctions and is undesirable because of the resultant de-saturated primary colors.

Referring now to Figure 8, an alternative front glass 800 was constructed using color separation filters 802 available from OCLI of California placed in a commercially available 3M brand Silverlux (TM) film matrix 806 which has greater than 95% reflectivity. All surfaces, generally designated 804, which are not within RGB squares are reflective of incident light arriving from the back lit side of the glass 800.

Figure 6 shows the spectral characteristics of the OCLI filters 802. Note that the vertical axis 600 represents transmittance and the horizontal axis 602 represents wave length in nanometers. Curves 604, 606 and 608 respectively represent blue, green and red light transmittance characteristics. The overlap area at point 610 between the blue and green filters is substantially less than for the absorbing glass assembly 400 as graphically illustrated in Figure 5 at point 510. These filters are of dichroic construction, so they reflect out of band light into the back light assembly while transmitting light which falls within the pass band of the color filter.

Another front glass assembly was constructed to hold an absorbing polarizer Sanritsu model 9218. Each of the front glass assemblies 400, 800 were placed in front of the back light assembly as shown in Figure 7.

Measured Increases Due to Utilization of Radiant Energy Conservation

Referring again to Figure 7, to confirm the potential gains which are obtained through the conservation of radiant energy in a back lit display a macro scale model was constructed to provide a means of measuring the increased display luminance for a constant luminous input such as the lamp 720. The model is considered to be a "macro scale" model because the glass plates 710 were made having approximately 170 times the aperture density of an LCD designed for a typical avionic application. The macro scale model had individual color apertures which were approximately one inch square distributed on a 6 x 8 inch glass substrate in a RGGB mosaic.

Relative areas between the active pixels and the interconnection areas were proportionately maintained in (i.e.,the model's plates had an aperture ratio of

approximately 50%). The lighting cavity 700 itself was the same size as the lighting cavity planned for use in an avionics application.

Two methods of measurement were used to measure the effects of adding the reflective color filters and reflective aperture mask. The first method of measurement used a calibrated 1980A Pritchard photometer located normal to the display surface and focused on a single green aperture of the glass plate under measurement. This method is referred to as the "green pixel" method hereinbelow.

The second method utilized a 40 inch diameter integrating sphere to collect the radiant energy emitted by the display surface in all directions. By affixing the face of the display to the sphere's large aperture such that all of the radiant energy from the display surface was emitted into the integrating sphere's cavity which is coated with a diffuse, highly reflective material such as Spectralon (TM). Another much smaller aperture on the integrating sphere was used to measure the radiant energy emitted by the display surface. A calibrated Pritchard 1980A photometer was focused onto the small aperture to measure the emitted radiation. This method of measurement eliminates the issue of direction from radiant energy measurements, and will be referred to as the "sphere" method of measurement hereinbelow.

A glass plate made of absorptive color filters, namely, Kodak Wratten gels, and black photographic tape was used to represent present art construction techniques for LCD's. The black photographic tape was used to represent the opaque row and column interconnection area on an LCD. The glass plate is referred to hereinbelow as the absorptive glass plate.

A second glass plate as was constructed from

reflective color filters, namely, OCLI's color separation filters, and reflective tape, namely, 3M Silverlux (TM) tape. The second glass plate was utilized to simulate the construction of a display utilizing the concepts described in this patent application. The second glass plate included reflective color filters and a reflective aperture mask.

Key for Measurement Table:

Box is defined to be the lighting cavity 700, the light source 720 and the electronics required to activate the light source.

Abs is defined to be the absorptive glass plate described above.

Ref is defined to be the reflective glass plate described above.

Pol is defined to be the absorptive polarizer (Sanritsu model 9218) glass plate described above.

The order of glass plate components listed below describes the physical location in front of the light source which was used for the particular measurement. For example, Box + Abs + Ref, indicates the absorptive plate was placed between the reflective glass plate and the light source within the box (i.e., the viewer saw the reflective plate's surface).

Multiple glass plates were used to eliminate gains associated with the higher in band transmission of the reflective color filters, and to maintain approximately the same color gamut. Multiple plates also enabled the insertion of the absorptive polarizer.

Measurement Condition	Green Pixel	Sphere
Box + Abs	77.7	92.8
Box + Ref	979	547
Box + Abs + Ref	71.7	16.0
Box + Ref + Abs	325	33.7
Box + Pol + Abs	34.6	9.3
Box + Pol + Ref	118.5	24.7
Box + Pol + Abs + Ref	27.6	No Measurement
Box + Pol + Ref + Abs	40.4	No Measurement

As can be seen above for every condition, insertion of the reflective plate in place of the absorptive plate or between the light source (Box) and the absorptive plate resulted in significant increases in the measured display luminance. An increase of 1260% for the green pixel measurement method was demonstrated for the (Box + Ref) versus (Box + Abs) condition. The sphere measurement method showed an increase of 590% for this same comparison. The smallest gain measured with the sphere method was 211% for the (Box + Pol + Abs) versus (Box + Pol + Ref) condition. While the smallest measured increase for the green pixel method was 146% for the (Box + Pol + Abs + Ref) versus (Box + Pol + Ref + Abs) conditions.

Description of Wire Grid Polarizer

Any polarizer which has minimal absorption of the incident radiant energy can be used to increase AMLCD luminous efficacy if it is used as described herein. Such a polarizer may be constructed from a grid of thin conductive wires which are aligned parallel to one another. The approximate width of the conductors needed to polarize the visible spectrum is 0.1 micrometers. These conductive wires must be aligned parallel to one another with a spacing of approximately 0.3 micrometers between wires.

The reflective polarizer described in this patent application, will offer the desirable feature of having a good extinction ratio for a broad angle of incidence of radiance. However, the most desirable feature is reflection of the incident radiation which is not aligned with the reflective polarizer's transmissive polarization axis. This presents the opportunity of returning this energy to the system by redirecting and "re-polarizing" the radiation such that it may pass through the reflective polarizer and the traditional polarizers to the display's observer.

Until the present invention, no wire grid polarizer has been constructed for operation in the visible spectrum. The wire grid polarizer is only one type of reflective polarizer which conserves radiant energy by returning untransmitted energy through reflection and other equivalent devices may be employed to accomplish the objectives of the instant invention. Wire grids have traditionally functioned as polarizers where their application has migrated upward along the electromagnetic spectrum as the technological improvements enabled devices with progressively smaller dimensions. This progression has continued for two reasons. The first reason is driven by the need for finer and finer detailed metallic structures for use within the semiconductor industry. Secondly, the high conductivity of metals has been maintained at the wavelengths of radiation previously considered. The conductivity of commonly available metals will decrease in the visible spectrum making this more of a limiting characteristic.

Wire grid polarizers manufactured in accordance with the present invention exhibit good extinction ratios over a broad spectrum as is shown, for example, in Figure 3 of "The Wire Grid as a Near-Infrared

Polarizer" by G. Bird and M. Parrish in Journal of the Optical Society of America, Volume 50, Number 9, pp 886-891, in 1960. The extinction ratio is controlled by the conductivity of the metal used to create the wire grid. The more conductive the wire material is, the broader the angle over which the polarizer's extinction ratio is acceptable. The first choice of common metals based upon this selection criterion would be silver, however, any metal which maintains a high fairly constant conductivity over the visible spectrum should work (e.g. Aluminum).

A wire grid polarizer made in accordance with the invention may be manufactured using well-known lithographic techniques such as employing, for example, an electron beam process for etching. Typical pitch between conductors for a reflective wire grid polarizer which will work in the visible spectrum should be approximately ¼ the wavelength of the radiation (~.2μm for green light).

Referring now to Figure 10, an LCD utilizing a reflective polarizer in accordance with one aspect of the invention is schematically illustrated. The apparatus shown in Figure 10 includes an LCD display 100 including a conventional LCD assembly 102, an absorbing rear polarizer 104, a reflecting wire grid polarizer 106, a back light cavity 108, and a fluorescent light source 110 of known serpentine construction. The conventional LCD assembly may include liquid crystal cells, a polarizer and a display glass. Ray 112, which extends from the fluorescent bulb source to surface 120 of the reflecting wire grid polarizer 106, represents emitted light from the fluorescent light source 110 having both p and s polarization. Ray 114, which extends from surface 120 to back plane 122, represents

reflected light of s polarization only. Ray 116, which extends from the wire grid polarizer 106 to outside of the view surface 102, represents transmitted light of p polarization only.

In one embodiment of the invention, the back light cavity is advantageously light tight and coated with diffusely reflective material. As a result, the reflected light of ray 114 is scrambled by the diffusely reflective material 107 which coats the back light cavity 108, including back plate 122. In this embodiment, the polarization axes of the wire grid polarizer 106 are aligned with the polarizing axes of the absorbing polarizer 104.

The reason for aligning a reflective polarizer with an absorbing rear polarizer as shown in Figure 10 may be better understood by examining an LCD's inherent ability to increase its contrast under high ambient illumination as illustrated by Figures 11 and 12.

Referring now to Figure 11, a simplified illustration of increased contrast for traditional LCDs under high ambient illumination is schematically illustrated. Shown is a reflective back light cavity 108, a first absorbing polarizer 130, a transmissive liquid crystal cell 132, a non-transmissive liquid crystal cell 134, and a second absorbing polarizer 136. The liquid crystal cells are advantageously polarization twisted in a well known manner. The first absorbing polarizer 130 transmits p polarized light. The second absorbing polarizer 136 transmits s polarized light. Ray 140 represents ambient illumination which enters the second absorbing polarizer and is reflected out along ray 144 after being reflected off of the back light cavity 108. Ray 142 represents ambient illumination absorbed in the

first polarizer 130.

Referring now to Figure 12, a simplified illustration of loss of an LCD's traditional advantage under high ambient illumination is shown. In contrast to Figure 11, only a reflective polarizer 150 is used here between the back light cavity and the liquid crystal cells. Shown in combination are a reflective back light cavity 108, a reflective polarizer 150, a transmissive liquid crystal cell 132, a non-transmissive liquid crystal cell 134, and an absorbing polarizer 136. The liquid crystal cells are polarization twisted in a well known manner. The reflective polarizer 150 transmits p polarized light. The absorbing polarizer 136 transmits s polarized light. Ray 152 represents ambient illumination which enters the absorbing polarizer and is reflected out along ray 154 after being reflected off of the back light cavity 108. Ray 156 represents ambient illumination reflected by the reflecting polarizer 150 to an observer along ray 158, thus eliminating a traditional LCD's increased contrast under high ambient illumination.

The reflecting polarizer is aligned with the traditional absorbing rear polarizer to maintain an LCD's inherent increased contrast in ambient illumination. Reflective metal used in the reflecting wire grid polarizer must maintain high conductivity over visible spectrum to ensure performance independent of wavelength. It is advantageous to vary the duty cycle of the reflecting polarizer by minimizing the width of the reflective portion to provide high transmission. Further improvement in the wire grid polarizer may be achieved by use of very conductive materials to achieve good extinction ratios and broad operable angle. Such a reflecting polarizer

results in high effective transmission through an LCD when combined with an efficient reflective back light cavity.

The invention has been described herein in considerable detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles and to construct and use such specialized components as are required. However, it is to be understood that the invention can be carried out by specifically different equipment and devices, and that various modifications, both as to the equipment details and operating procedures, can be accomplished without departing from the scope of the invention itself.

What is claimed is:

10. The radiant energy conservation LCD display (100) of claim 8 wherein the reflecting polarizing means (106) comprises a wire grid polarizer (106).

11. The radiant energy conservation LCD display (100) of claim 8 wherein the liquid crystal display assembly (100) further comprises an absorptive color filtering means (104) aligned with the viewing surface (102) and a plurality of dichroic filters (402) aligned with the absorptive color filtering means (104) and the viewing surface (102).

12. The radiant energy conservation LCD display (100) of claim 11 wherein the display assembly (100) further includes a specularly reflective aperture mask positioned around the plurality of dichroic filters (402).

13. The radiant energy conservation LCD display (100) of claim 8 wherein the reflecting polarizing means (106) comprises a wire grid polarizer (106).

14. The radiant energy conservation LCD display (100) of claim 10 wherein the wire grid polarizer (106) comprises a grid comprised of a plurality of conductors (106) arranged in parallel to each other and suitably spaced apart so as to transmit light (112) in a visible spectrum having a first polarization (116) and reflect light (112) in the visible spectrum having a second polarization (114).

15. The reflecting polarizer (106) of claim 14 wherein the plurality of conductors (106) comprise metal conductors.

16. The reflecting polarizer (106) of claim 14 wherein the plurality of conductors (106) comprises a plurality of metal wires having a width of at most about .1 micrometers.

17. The reflecting polarizer (106) of claim 16 wherein the plurality of metal wires (106) are spaced apart by about .3 micrometers or less.

18. The reflecting polarizer (106) of claim 14 wherein the plurality of conductors (106) comprise metal wires substantially comprised of material selected from the group consisting of aluminum, copper, silver, gold, nickel and platinum.

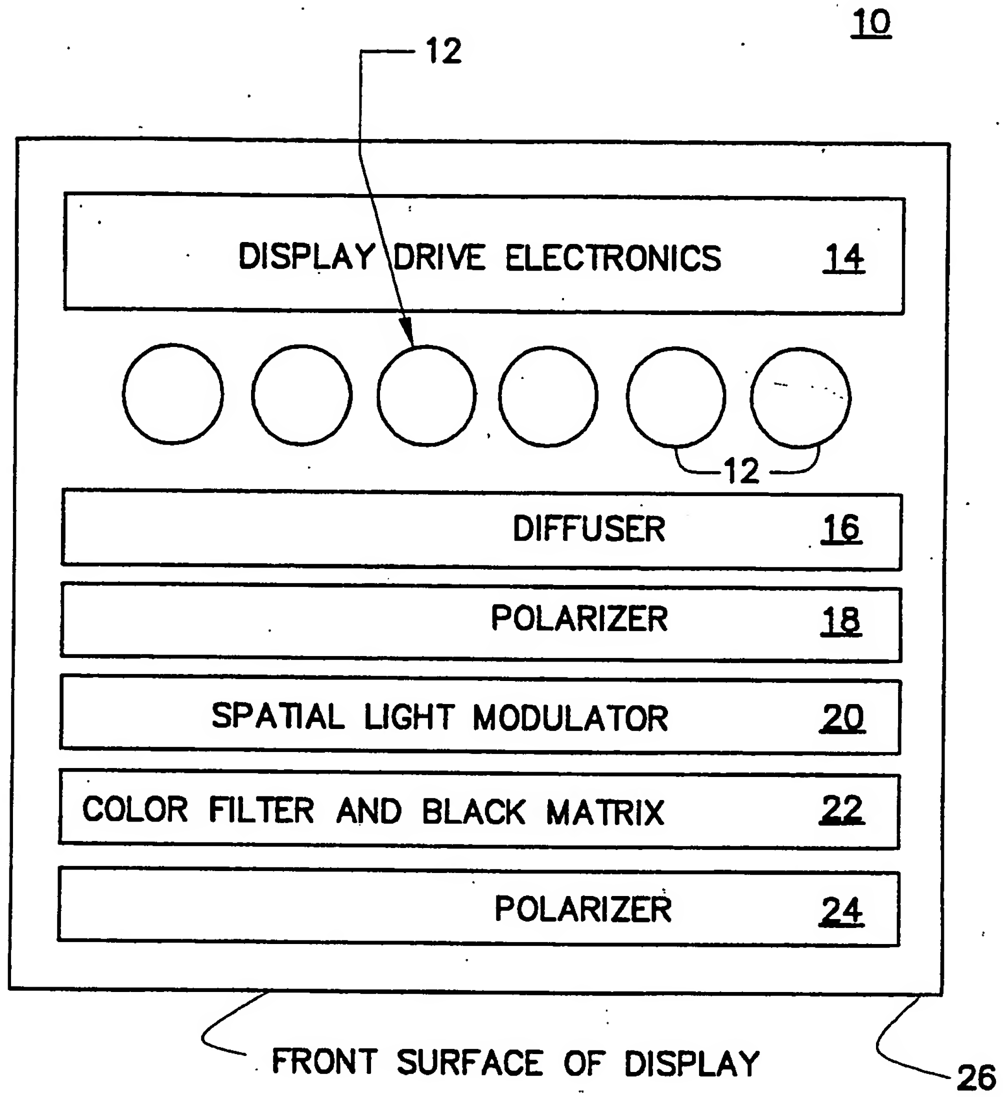

Fig. 1
(PRIOR ART)

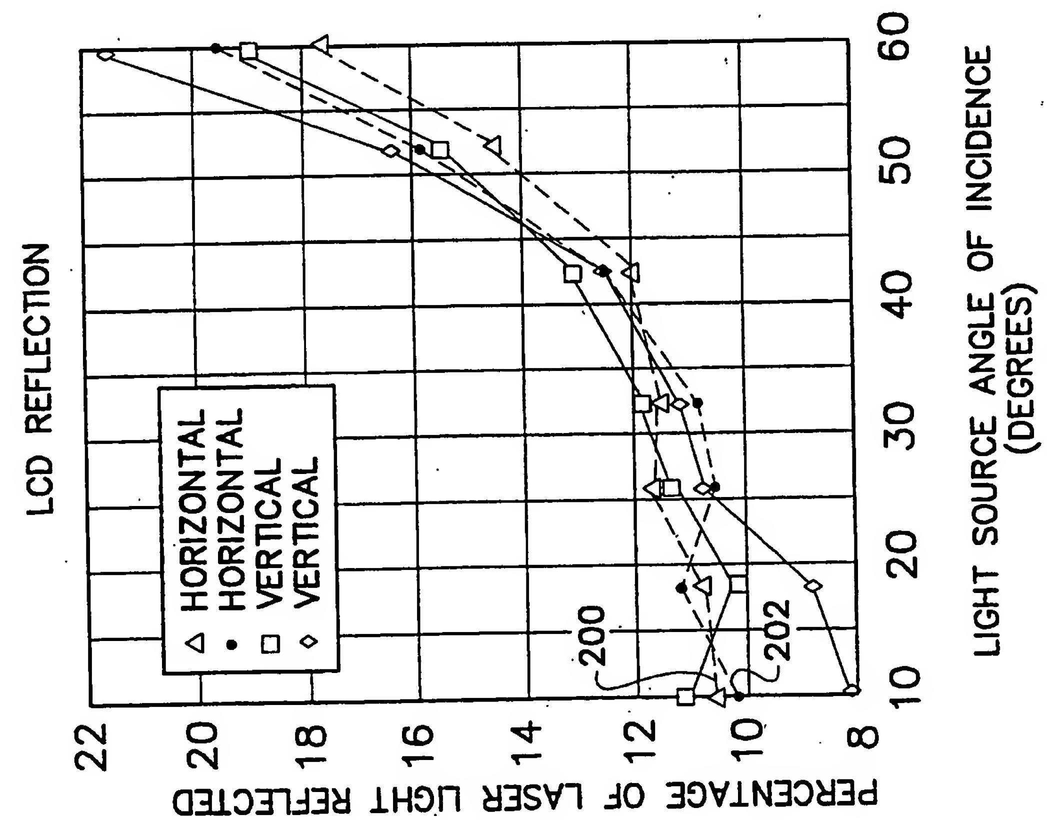
LCD REFLECTION
PERCENTAGE OF LASER LIGHT REFLECTED
22
20
18
16
14
12
10
8
10
20
30
40
50
60
LIGHT SOURCE ANGLE OF INCIDENCE
(DEGREES)
HORIZONTAL
HORIZONTAL
VERTICAL
VERTICAL
200
202

Fig.2A

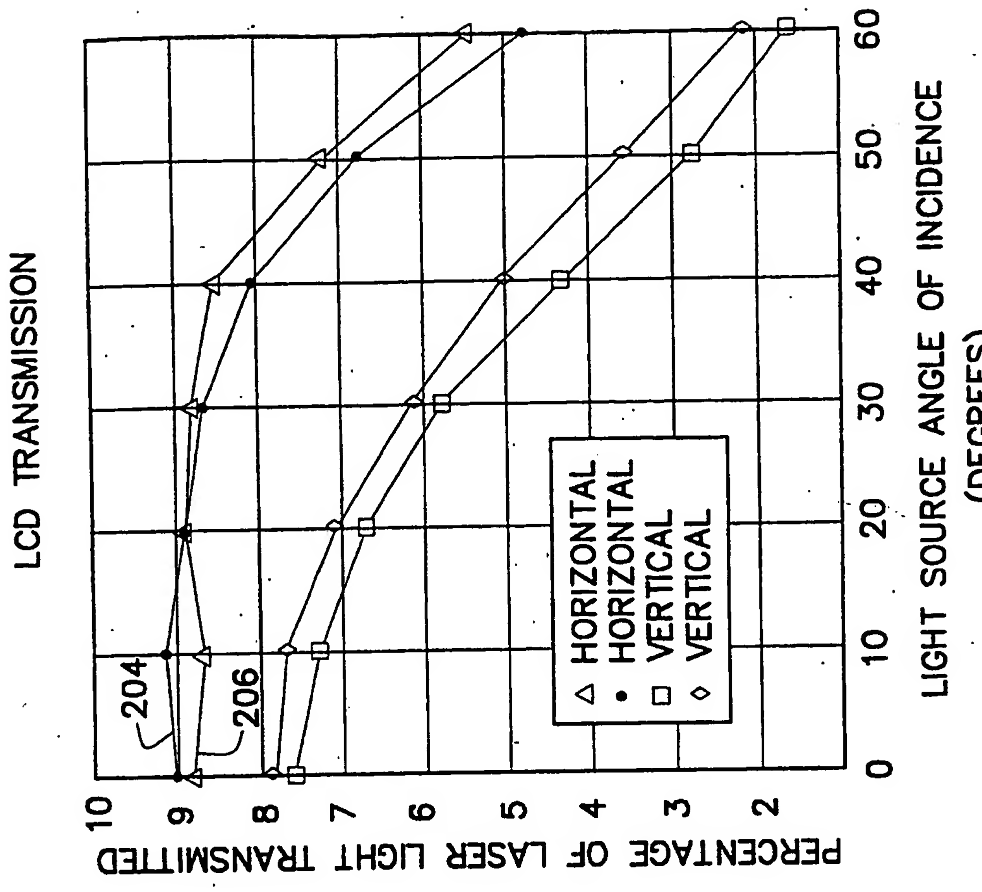
LCD TRANSMISSION
PERCENTAGE OF LASER LIGHT TRANSMITTED
10
9
8
7
6
5
4
3
2
0
10
20
30
40
50
60
LIGHT SOURCE ANGLE OF INCIDENCE
(DEGREES)
HORIZONTAL
HORIZONTAL
VERTICAL
VERTICAL
204
206

Fig.2B

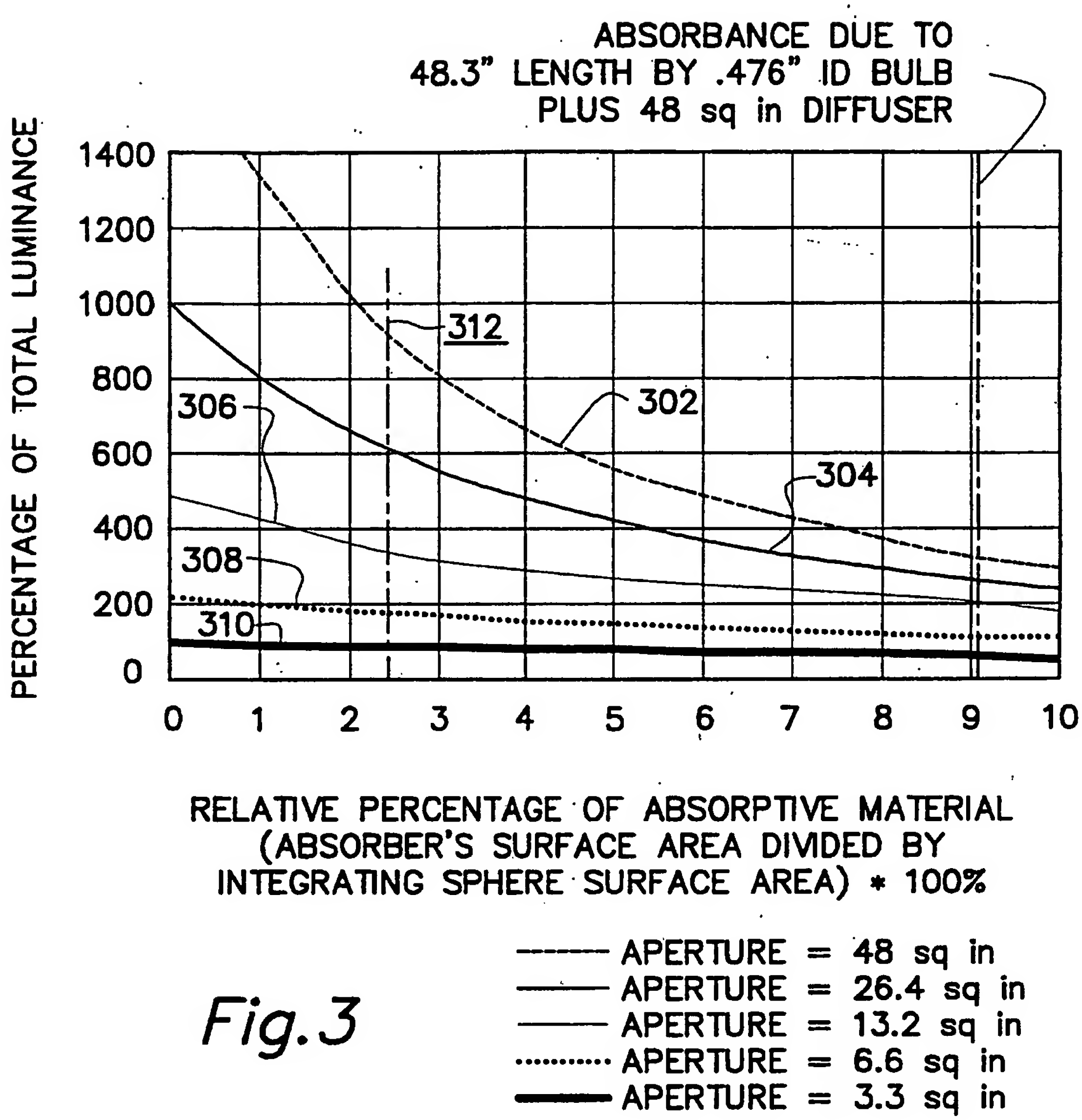
ABSORBANCE DUE TO
48.3" LENGTH BY .476" ID BULB
PLUS 48 sq in DIFFUSER
PERCENTAGE OF TOTAL LUMINANCE
1400
1200
1000
800
600
400
200
0
312
306
302
304
308
310
0
1
2
3
4
5
6
7
8
9
10
RELATIVE PERCENTAGE OF ABSORPTIVE MATERIAL
(ABSORBER'S SURFACE AREA DIVIDED BY
INTEGRATING SPHERE SURFACE AREA) * 100%
APERTURE = 48 sq in
APERTURE = 26.4 sq in
APERTURE = 13.2 sq in
APERTURE = 6.6 sq in
APERTURE = 3.3 sq in

Fig.3

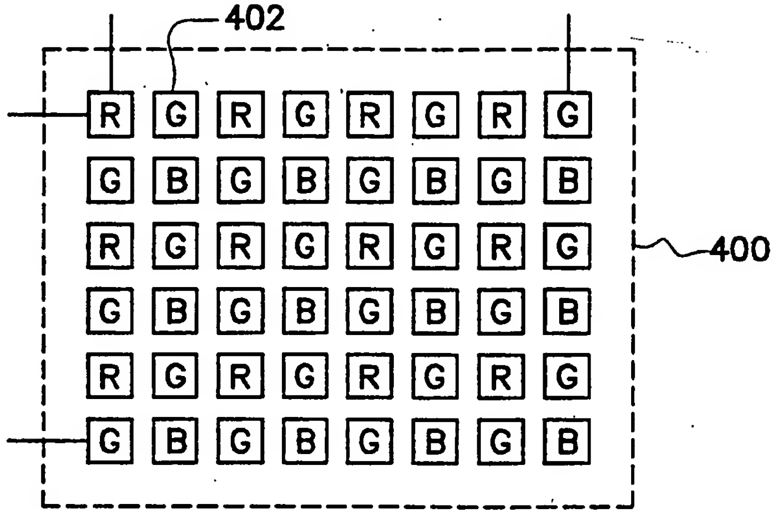
402
400
R G R G R G R G
G B G B G B G B
R G R G R G R G
G B G B G B G B
R G R G R G R G
G B G B G B G B

Fig. 4

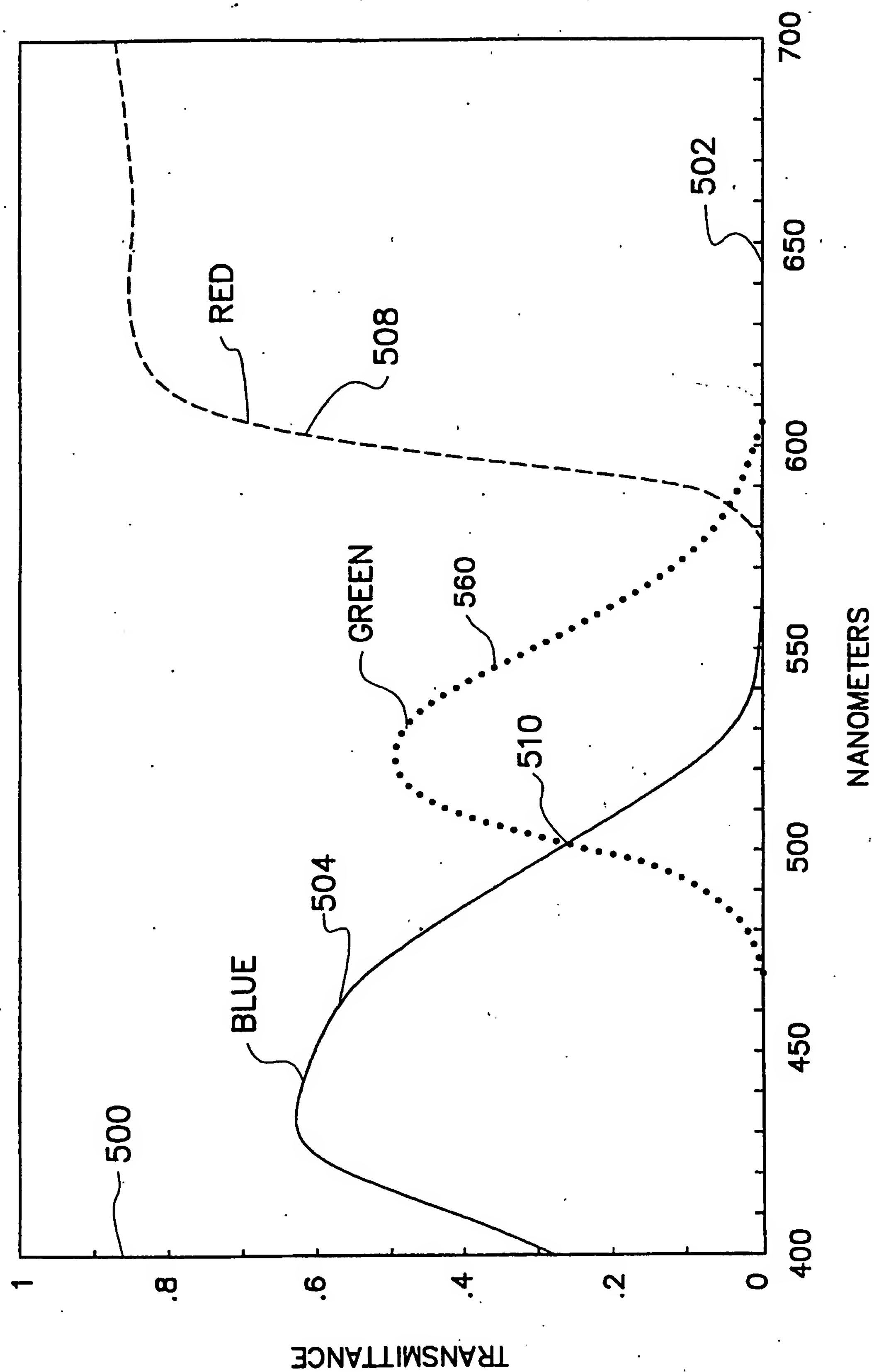
TRANSMITTANCE
1
.8
.6
.4
.2
0
NANOMETERS
400
450
500
550
600
650
700
500
BLUE
504
510
GREEN
560
RED
508
502

Fig.5

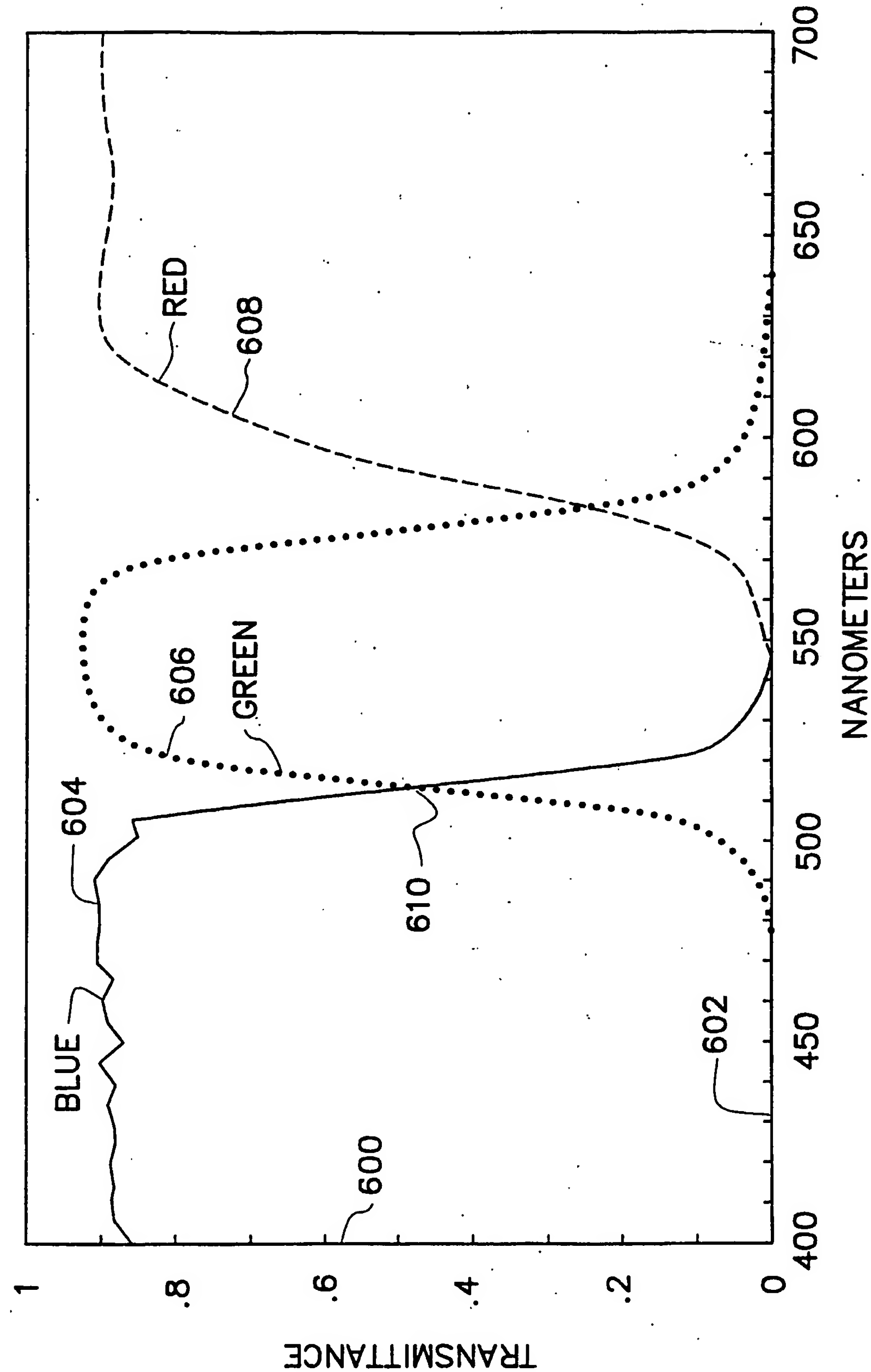
TRANSMITTANCE
1
.8
.6
.4
.2
0
400
450
500
550
600
650
700
NANOMETERS
BLUE
604
600
602
610
606
GREEN
RED
608

Fig.6

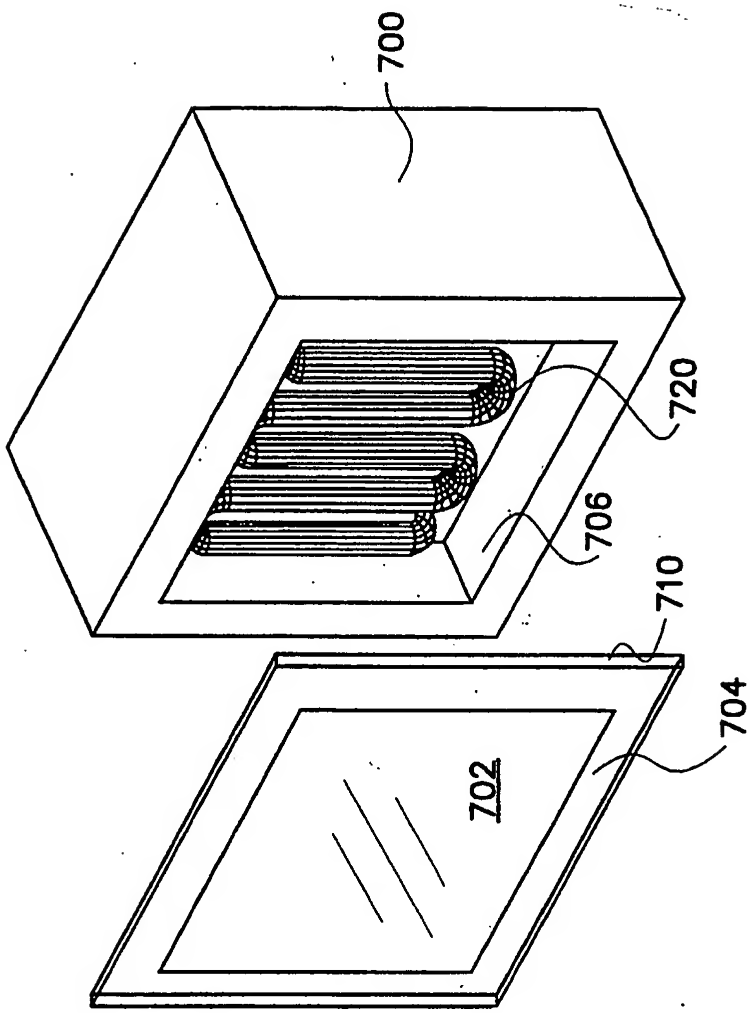

Fig. 7

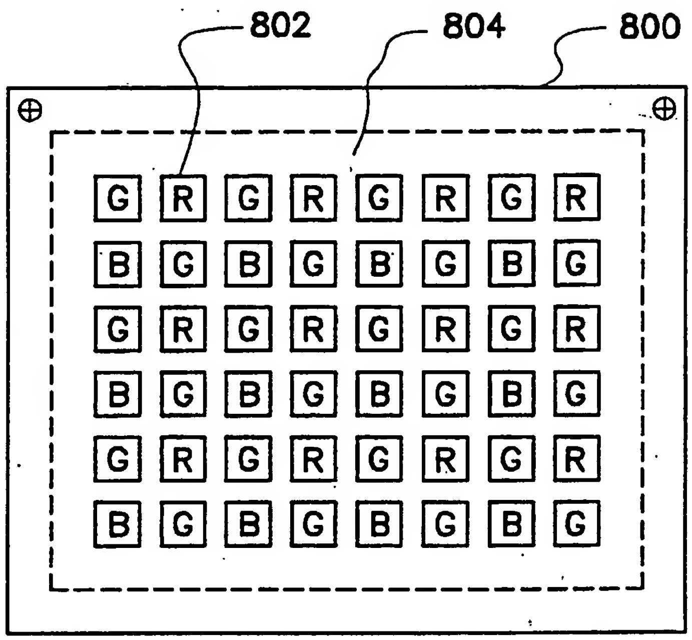
802
804
800
G R G R G R G R
B G B G B G B G
G R G R G R G R
B G B G B G B G
G R G R G R G R
B G B G B G B G

Fig.8

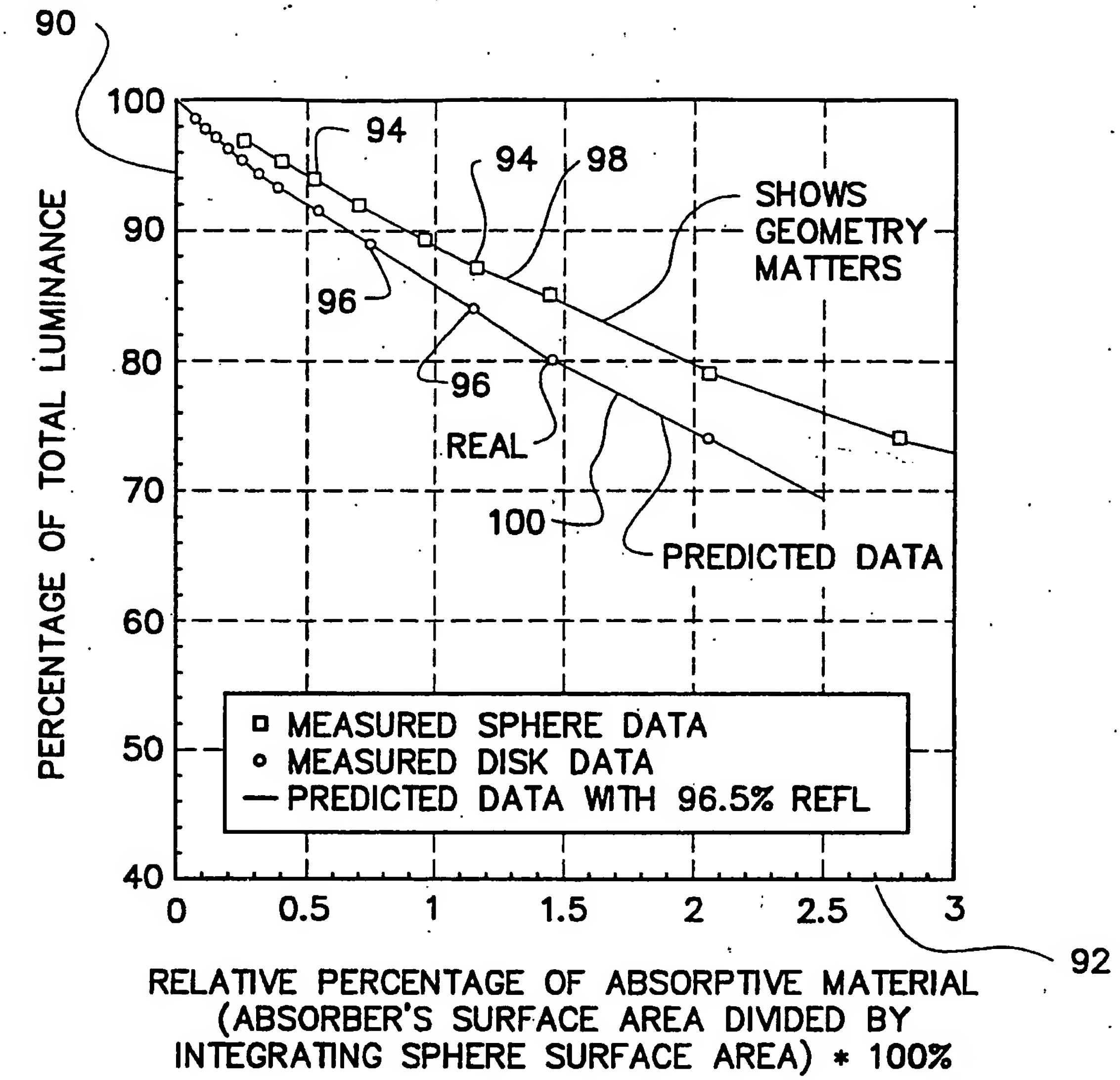
90
100
90
80
70
60
50
40
0
0.5
1
1.5
2
2.5
3
94
94
98
96
96
SHOWS GEOMETRY MATTERS
REAL
100
PREDICTED DATA
PERCENTAGE OF TOTAL LUMINANCE
MEASURED SPHERE DATA
MEASURED DISK DATA
PREDICTED DATA WITH 96.5% REFL
92
RELATIVE PERCENTAGE OF ABSORPTIVE MATERIAL (ABSORBER'S SURFACE AREA DIVIDED BY INTEGRATING SPHERE SURFACE AREA) * 100%

Fig. 9

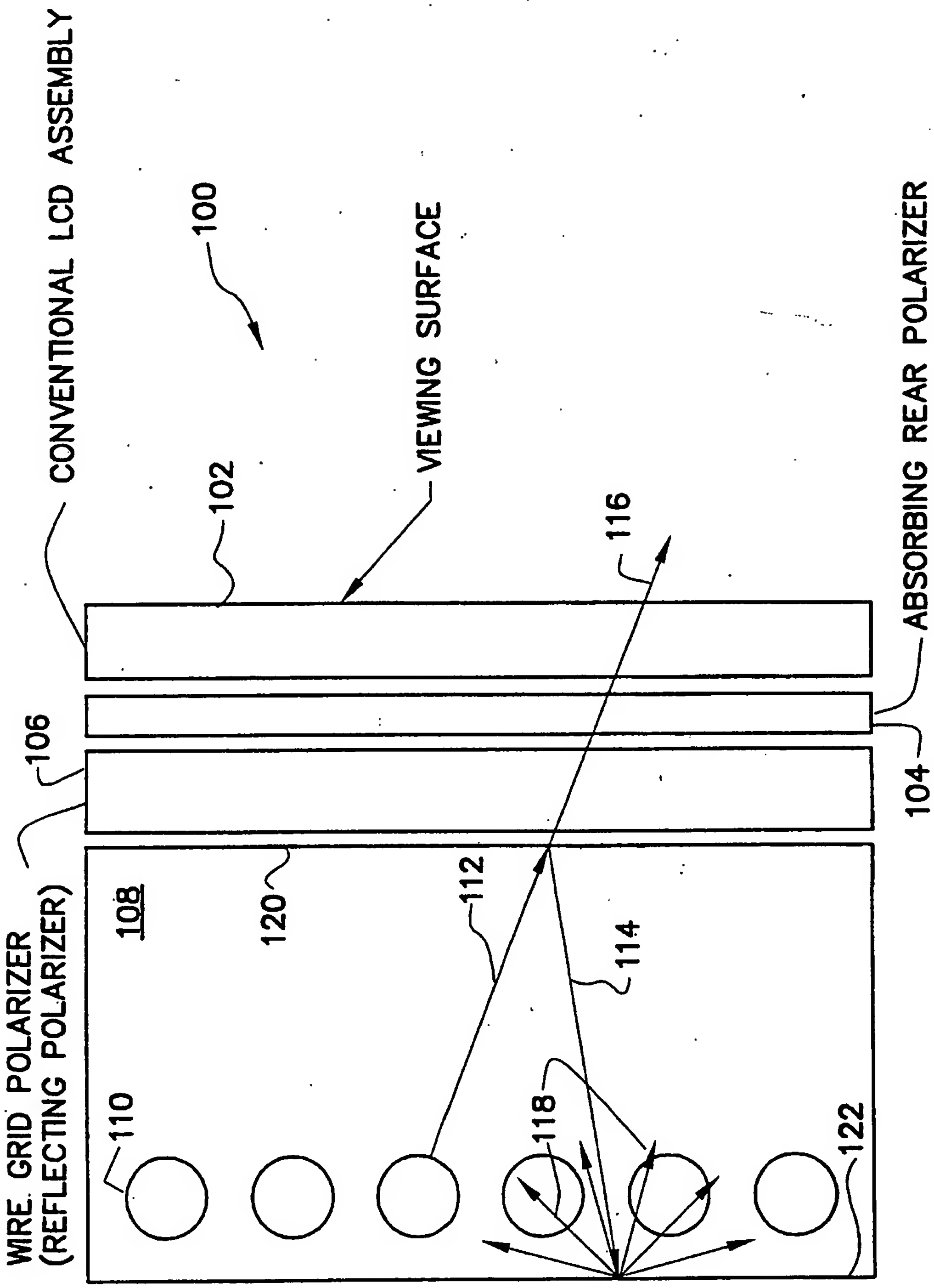
CONVENTIONAL LCD ASSEMBLY
100
VIEWING SURFACE
102
116
ABSORBING REAR POLARIZER
106
104
WIRE GRID POLARIZER
(REFLECTING POLARIZER)
108
120
112
114
110
118
122

Fig.10

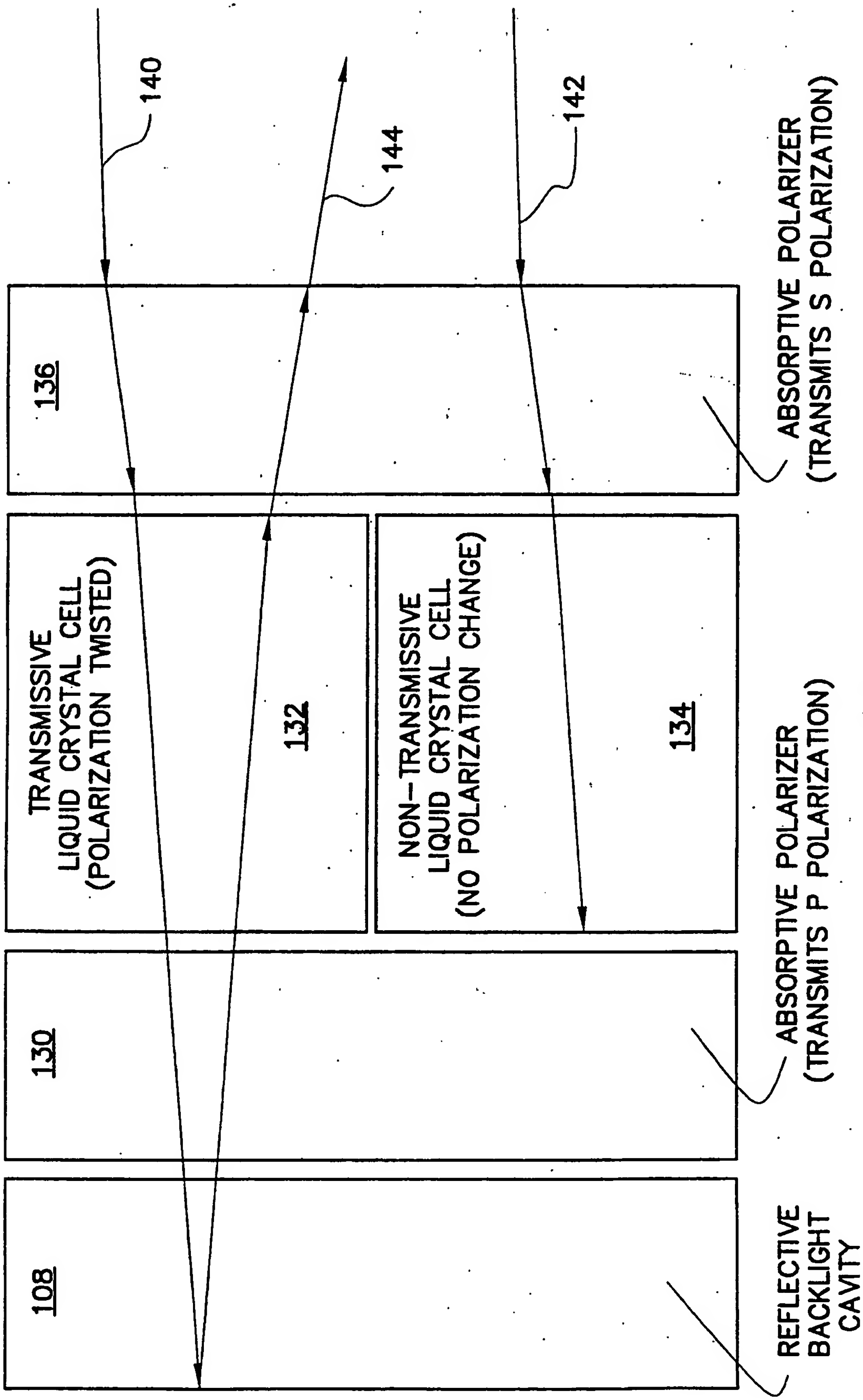
140
144
142
136
ABSORPTIVE POLARIZER
(TRANSMITS S POLARIZATION)
TRANSMISSIVE
LIQUID CRYSTAL CELL
(POLARIZATION TWISTED)
132
NON-TRANSMISSIVE
LIQUID CRYSTAL CELL
(NO POLARIZATION CHANGE)
134
130
ABSORPTIVE POLARIZER
(TRANSMITS P POLARIZATION)
108
REFLECTIVE
BACKLIGHT
CAVITY

Fig.11

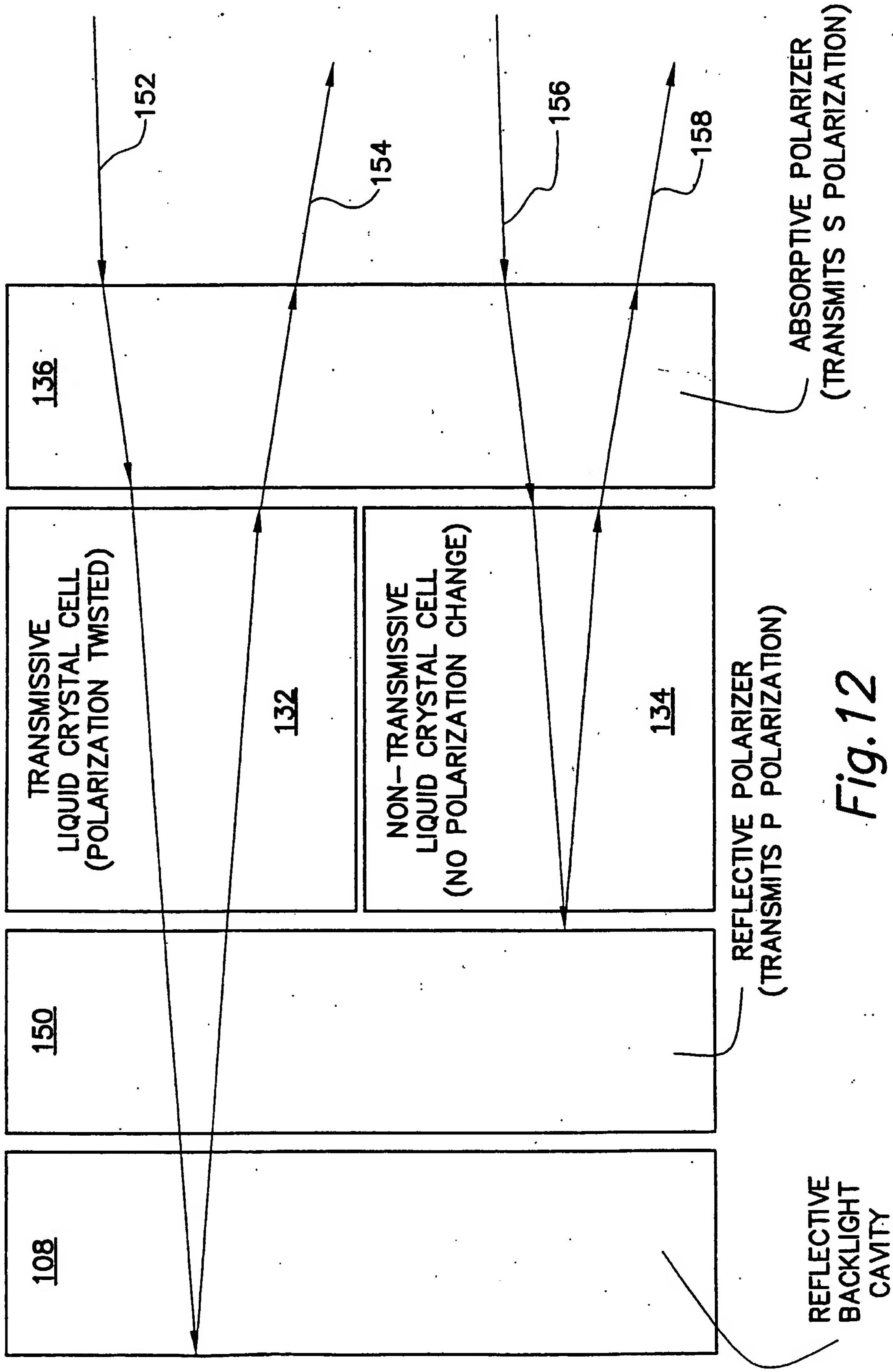
152
154
156
158
136
ABSORPTIVE POLARIZER
(TRANSMITS S POLARIZATION)
TRANSMISSIVE
LIQUID CRYSTAL CELL
(POLARIZATION TWISTED)
132
NON-TRANSMISSIVE
LIQUID CRYSTAL CELL
(NO POLARIZATION CHANGE)
134
150
REFLECTIVE POLARIZER
(TRANSMITS P POLARIZATION)
108
REFLECTIVE
BACKLIGHT
CAVITY

Fig.12

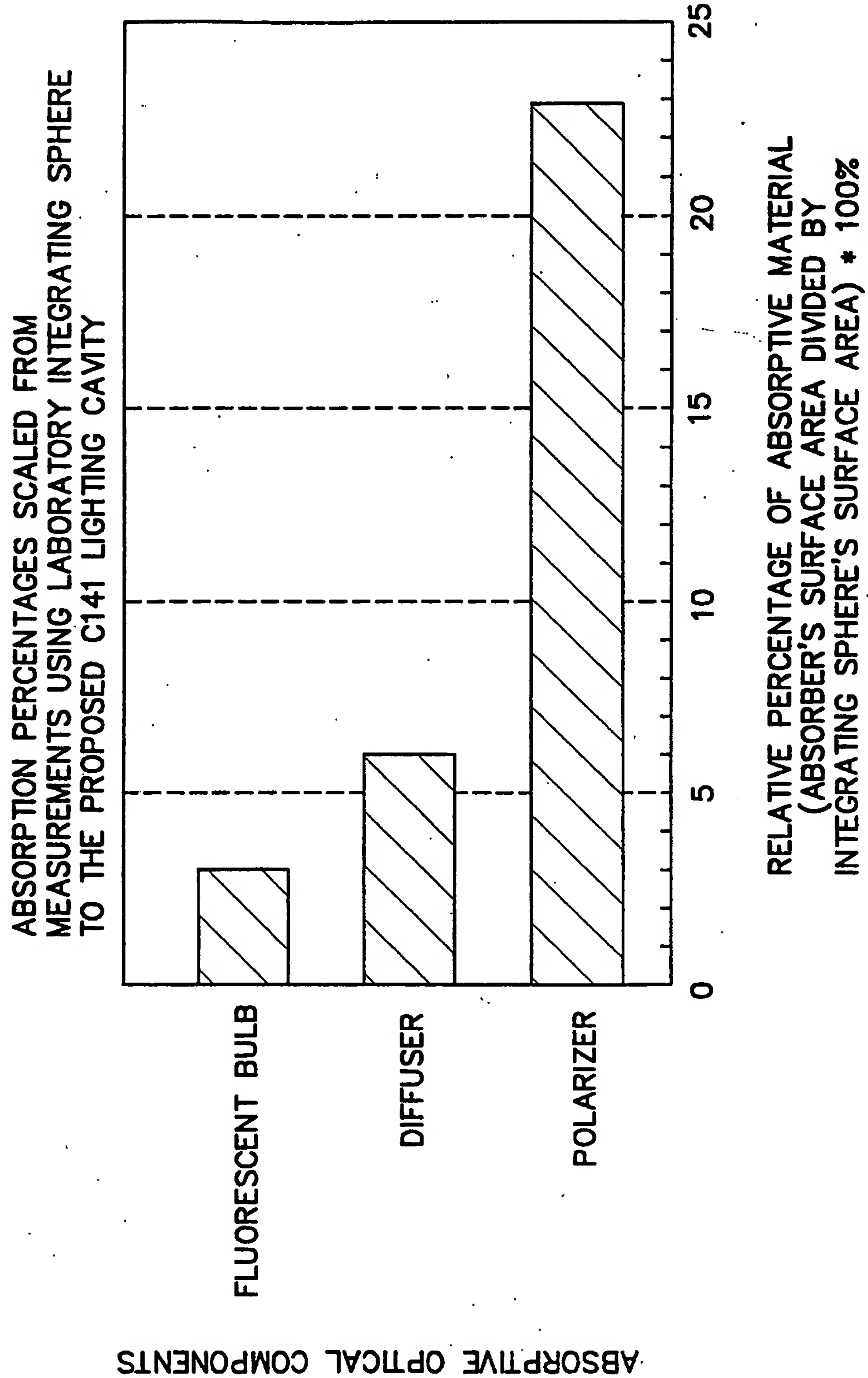
ABSORPTION PERCENTAGES SCALED FROM
MEASUREMENTS USING LABORATORY INTEGRATING SPHERE
TO THE PROPOSED C141 LIGHTING CAVITY
FLUORESCENT BULB
DIFFUSER
POLARIZER
0
5
10
15
20
25
RELATIVE PERCENTAGE OF ABSORPTIVE MATERIAL
(ABSORBER'S SURFACE AREA DIVIDED BY
INTEGRATING SPHERE'S SURFACE AREA) * 100%
ABSORPTIVE OPTICAL COMPONENTS

Fig.13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/10799

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 506 (P-1440)20 October 1992 & JP,A,04 184 429 (SEIKO EPSON CORP) 1 July 1992 see abstract; figure 4	8,9
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 418 (P-1413)3 September 1992 & JP,A,04 141 603 (SEIKO EPSON CORP) 15 May 1992 see abstract; figure 5	8,9
A	EP,A,0 337 555 (PHILIPS NV) 18 October 1989 see abstract see column 1, line 52 - column 5, line 20 see claims 1-6,10,11; figures 1,3	1,2,4,5

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

3

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 1994	09.03.94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Iasevoli, R